ANALYZING THE EFFECTS OF DEPTH OF CUT AND SPINDLE SPEED ON GRINDING WHEEL TO IMPROVE THE SURFACE FINISH

A Thesis

Submitted

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for the degree of

MASTER OF TECHNOLOGY

In

PRODUCTION & INDUSTRIAL ENGINEERING

Submitted by

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DECEMBER, 2022

CERTIFICATE

This is to certify that **Mr. Nitish Yadav (Enrollment no-1900103702)** has carried out the research work presented in the thesis titled "**Analyzing the effects of depth of cut and Spindle Speed on Grinding Wheel to improve the surface finish"** submitted for partial fulfillment for the award of the **Degree of Master of Technology** in **Production & Industrial Engineering** from **Integral University, Lucknow** under my supervision.

It is also certified that:

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Prof (Dr.) P.K Bharti
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Date:
Place: Lucknow

DECLARATION

I hereby declare that the thesis titled "**Analyzing the effects of depth of cut and Spindle Speed on Grinding Wheel to improve the surface finish"** is an authentic record of the research work carried out by me under the supervision of **Prof(Dr.) P.K Bharti (Head, Department of Mechanical Engineering)** for the period from **August-2019 to December-2022** at **Integral University, Lucknow.** No part of this thesis has been presented elsewhere for any other degree or diploma earlier.

I declare that I have faithfully acknowledged and referred to the works of other researchers wherever their published works have been cited in the thesis. I further certify that I have not willfully taken other's work, para, text, data, results, tables, figures etc. reported in the journals, books, magazines, reports, dissertations, thesis, etc., or available at web-sites without their permission, and have not included those in this M-Tech thesis citing as my own work. All collaborations and critiques that have contributed to giving the thesis its final shape is duly acknowledged and credited. The experimental work is almost entirely my own work, the collaborative contributions have been indicated clearly and acknowledged.

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ABSTRACT

Grinding is the early most process of removal of material to give the desired end result. The material removed is most commonly the powdered form of original material. The most ordinary example which we see around is the making of flour from wheat. In this process wheat granules are crushed between two Sand stones, thus the constant rubbing of two stone converts wheat into powdered form of flour. All the grinding wheels thus work on the same principal of frictional removal of metal. Grinding wheel removes metal from the original job and completes the finishing process. Grinding is a subset of cutting, as grinding is a true metal-cutting process. Each grain of abrasive functions as a microscopic single-point cutting edge (although of high negative rake angle), and shears a tiny chip that is analogous to what would conventionally be called a "cut" chip (turning, milling, drilling, tapping, etc.). However, among people who work in the machining fields, the term cutting is often understood to refer to the macroscopic cutting operations, and grinding is often mentally categorized as a "separate" process. This is why the terms are usually used separately in shop-floor practice. Grinding efficiency is one of the most important considerations the selection of grinding operation conditions because it has a significant impact on the productivity, quality, energy consumption and cost. Focusing on the core issues of grinding process, the paper presents some fundamental research findings in relation to grinding material removal mechanisms. The surface finishing operation performed here is dependent on Feed Rate (Vc) and the Depth of Cut being provided. Spindle speed or grinding wheel speed Vw being constant has its impact on surface finish when combined with the depth of cut being provided. The time period in which the whole surface of the job is finished is directly proportional to the Feed Rate being provided. As the feed rate increases the time taken in grinding of the surface decreases, though it does not guarantee a good surface finish. And thus factors like wheel composition, depth of cut, spindle speed, feed rate are managed to give good surface

finish. In the thesis work is restricted to selection of grinding wheel and effect of cutting speed and depth of cut.

Grinding is a critical manufacturing process and is often the only alternative when producing precision components or when machining brittle materials such as ceramics. Characterizing and modeling the surface finish in the grinding process is a difficult task due to the stochastic nature of the size, shape and spatial distribution of abrasive grains that make up the surface of grinding wheels. Since the surface finish obtained in grinding is a direct function of the wheel surface topography, which is conditioned by a single point dressing process, understanding the effects of grinding parameters on the wheel topography is essential. Therefore, the main objectives of this thesis are:

1) To experimentally characterize the effect of Depth of cut with respect to spindle speed on the job surface.
2) To determine the effects of single point dressing conditions on the wheel surface topography.
3) To analyze the cutting speed, which directly impacts the time period within which whole surface is being grinded?

The overall experiments are being done on a Praga Tool and Cutter Grinding machine with a spindle speed of 1200RPM , 1500RPM and 1800RPM. The grinding wheel being used is compatible for Mild Steel Flat. The experiments are carried out with change in Depth of cut. Since spindle speed is constant the main effects which we can work upon are the time period of grinding process which is almost dependent on the depth of cut as the material quality and pre experimental surface evenness is same for all the experimental jobs. In total 10 exercises are performed and the surface finish is measured with the help of Dial Test Indicator (DTI) which is capable of noticing the slightest of the change. With machine and equipment restrictions, the study of lay behavior with naked eye and the direction study also gives glimpse of proper combination which could be followed for the best surface finish.

A grinding wheel is a combination of abrasive and bonding material, thus many factors affect the efficiency of grinding wheel and overall surface finish. The primary factors being considered are grade and grit of the abrasive. The Loading and Glazing of wheel is also the foremost thing under consideration. Thus dressing of wheel is done to remove the loading and glazing. Further study is required to get a combination of affects which can guarantee longevity of tool life and gives good surface finish.

CHAPTER 1

INTRODUCTION

1.1 Problems And Motivation

Grinding is one of the oldest machining processes and has been used since the stone ages to accomplish such tasks as creating hunting tools. Times have changed and now precision grinding is a complex machining process widely used to produce precision components such as bearing rings, lenses, and structural components. Even with lower production speeds, the grinding process is often preferred due to its ability to produce superior surface finish, and is often the only alternative when finishing brittle materials such as tool steels, ceramics, and optical materials. One of the first and main determining factors of the final ground surface quality is the dressing of the grinding wheel. The relationship of the dressed grinding wheel topography and ground surface finish is very important and is greatly affected by the dressing process. The ability to accurately simulate the grinding wheel topography after dressing would aid in increasing the efficiency of the grinding process resulting in greater number of high quality parts produced in less amount of time. Precision grinding wheels are very complex due to the stochastic nature of abrasive grains, which are randomly placed within the volume of the grinding wheel that consists of a bonding material and porosity created during the wheel manufacturing process. Traditionally, efforts to study the three-dimensional grinding wheel surface as a function of the dressing condition has focused on either conventional aluminum oxide or super-abrasive wheels such as diamond. Moreover considering raw material of the exercise carrying out here Aluminium oxide wheel is used of desired grade and grit size. When studying about the surface texture of both wheel and the grinding surface every factor plays an important role in defining the rate of grinding wheel tool wear and the surface finish being achieved. In industries, the prime objective in grinding process is to get a better surface finish or to get high material removal rate (MRR) of the work piece. Better surface finish can be obtained by using fine grained grinding wheel whereas higher MRR can be obtained from the coarse grained grinding wheel. Fine grained topography is obtained by providing a lower dressing depth and dressing the wheel for a short amount of time while coarse grained topography is obtained by providing a greater dressing depth and dressing the same wheel for more time duration (Pande and Lal, (1979))[3]. Pattinson and Chiholm (1972) [3] studied the effect of dressing cross feed rate on radial wheel wear and number of active cutting edges

The surface of the grinding wheel changes as a result of the interaction of the diamond dresser with the abrasive grains and bond material. Surface metrology techniques have advanced in recent years and now allow for more precise methods for measuring the complex surface texture of grinding wheels. Scanning electron microscopes are very useful to provide qualitative information and are generally used in combination with other measurement methods that can describe the surface quantitatively. A superior measurement apparatus is necessary to measure the surface and how it changes as a function of the dressing conditions such as in feed, which represents the depth the diamond dresser engages into the wheel surface, and how fast it traverses across the wheel (dressing lead). Different methodologies for measuring the surface of grinding wheels ranging from simple two-dimensional contact methods to advanced three-dimensional scanning instrumentation need to be explored to precisely describe the surface of the grinding wheel.

In order to describe the transformation of the wheel surface due to dressing, it is important to fully understand and characterize the grinding wheel surface topography and how it changes throughout the dressing process. Grinding wheels are typically described in terms of the surface texture height distribution, abrasive grain size distribution, and grain density. The question is if there are other characteristic parameters that should be used to describe the grinding wheel surface topography as precisely as possible.

Stochastic simulation models are often used to describe the wheel surface since the grinding wheel surface topography consists of randomly distributed abrasive grains, bonding material, and porosity. This modeling technique is often chosen since the fracture and/or dislodgement of an abrasive grain from the bond is complex and depends on many random factors such as the dressing load, extent of adhesion between the bond and the grain, fracture toughness of the abrasive, and stress concentrations at the grain-bond interface.

Verification of the resulting simulation of the precision grinding wheel surface topography is needed to determine its validity, which is often overlooked in previously reported models. Simulations can be validated in both qualitative and quantitative terms. The majority of existing grinding wheel topography simulation models result in geometry that lacks the realism of an actual grinding wheel surface topography. Quantitative 4 validations of wheel surface topography models are often limited by the ability of the measurement and analysis equipment.

1.2 Research Objectives

The main focus of this research is to accurately characterize, model, and understand how the surface topography of a precision grinding wheel changes during the single point diamond dressing process. The specific objectives of this work are as follows:

1. Surface finishing operation performed here is dependent on Feed Rate (Vc) and the Depth of Cut being provided.
2. Spindle speed or grinding wheel speed Vw being constant has its impact on surface finish when combined with the depth of cut being provided.

1. Provided
2. The time period in which the whole surface of the job is finished is directly proportional to the Feed Rate being provided.
3. Validating the wheel surface topography by Dial Test Indicator.

The work to be used is flat steel mild steel. The cutting tool used is an aluminum-based grinding wheel of prescribed specifications. Machining takes place at constant feed and at different speeds and depths of cut. This table summarizes the settings for the most important machining parameters. In this work, we attempt to investigate the effect of dressing parameters on wheel topography and measure it with respect to the minimum surface roughness (Ra) during surface grinding of mild steel bars. A design of experiment based on the L9 Orthogonal Array is used to examine interactions and checks between factors. In the current work, we used experimental results to find an analysis of variance (ANOVA) that describes the importance of parameters on responses. Appropriate correlations between input parameters and response surface roughness are established and finally predicted values are validated and compared with experimental results [4]

1.3 Thesis Outline

Chapter one starts with the explanation of the work being done in the Thesis. It also includes the various problems motivations in doing this thesis. Thesis outline and objective have been explained with proper Literature Review done and explained. The main focus of this research is to accurately characterize, model, and understand how the surface topography of a precision grinding wheel changes during the single point diamond dressing process.

Chapter 2 describes the grinding wheel composition, its nomenclature, various aspects of grinding wheel composition and may others. Various profiles and cross sections are available depending on the intended usage for the wheel. They may also be made from a solid steel or aluminum disc with particles bonded to the surface. Today most grinding wheels are artificial composites made with artificial aggregates. All the possible compositions is studied and wheel nomenclature is given to understand the usage of the wheel. Grinding wheel applications, grinding wheel defects and the factors on which selection of grinding wheel depends has been studied.

The third chapter of this thesis begins with an overview of different parameters on which grinding wheel surface and good grinding practice depends. The factors responsible for surface finish, longevity of grinding wheel tool life and accuracy of job all are dependent on many factors which have been listed their .There understanding is important for the best possible composition of data. By considering each of these seven factors, you can narrow down your list of options for starting the sharpening process. It's easier than you think. A small list of options to start the grinding process. First Considerations When Choosing a Wheel Type The first thing to consider when choosing a wheel specification is what you are going to grind. What is the material and hardness? Is it easy or difficult to sharpen? Knowing these factors will help you choose the right abrasive type, particle characteristics, appropriate particle size, and binder type.

Chapter 4 of the thesis describes the characterization of the grinding wheel surface using various types of measurement equipment. Precision grinding wheels are often difficult to characterize due to the stochastic nature of abrasive grinding grains, which are randomly distributed on the wheel surface. The wheel characterization study is broken into two main components including characterization of the wheel surface and characterization of the individual grits/grains. This also explains the various combinations best suited for good finish while varying the feed rate.

Single point dressing experiments on Aluminium oxide grinding wheels are performed and summarized in Chapter 5. The experimental grinding wheel dressing trials are performed on a Aluminium oxide grinding wheel using a single point diamond dresser mounted on a surface grinding machine. The surface of the grinding wheel is measured using Dial Test Indicator instrumentation to measure surface evenness. The experiment was designed using the Taguchi method which uses OA (orthogonal arrays) to explore the parametric space with some experiments. Two parameters were selected in this study: cutting speed and depth. Selection of a particular OA (orthogonal array) is based on the number of levels of various factors. Here, 3 parameters each at 3 levels have been taken. The output is analyzed using ANOVA. All these experiments tells about the best possible combination of spindal speed feed rate and depth of cut for the Mild steel flat, to give the best Ra number i.e. surface roughness number.

CHAPTER 2

GRINDING WHEEL

2.1 Grinding Wheel Composition

Grinding wheels in general mainly contain abrasive compounds or materials with abrasive properties. Such wheels are used as cutting tool in grinding machines. The wheels are generally made with composite material . This consists of coarse-particle pressed and bonded together by a bonding material to form a solid and then given the desired shape and size viz. circular shape. Various profiles and cross sections are available depending on the intended usage for the wheel. They may also be made from a solid steel or aluminum disc with particles bonded to the surface. Today most grinding wheels are artificial composites made with artificial aggregates, but the history of grinding wheels began with natural composite stones, such as those used for millstones. The manufacture of these wheels is a precise and tightly controlled process, due not only to the inherent safety risks of a spinning disc, but also the composition and uniformity required to prevent that disc from exploding due to the high stresses produced on rotation. Grinding wheels are consumables, although the life span can vary widely depending on the use case, from less than a day to many years. As the wheel cuts, it periodically releases individual grains of abrasive, typically because they grow dull and the increased drag pulls them out of the bond. Fresh grains are exposed in this wear process, which begin the next cycle. The rate of wear in this process is usually very predictable for a given application, and is necessary for good performance. [6]

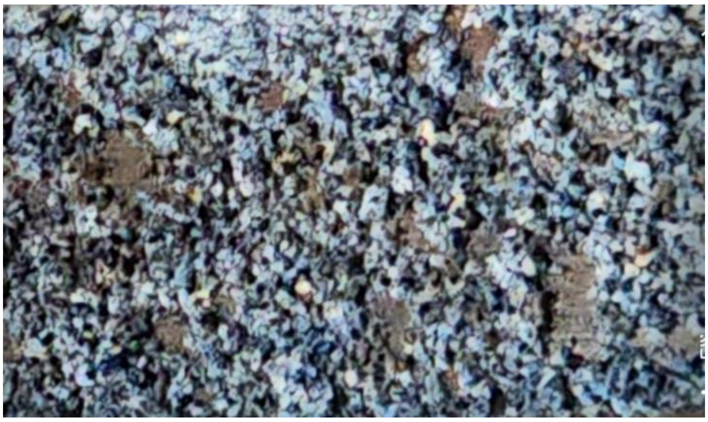

Figure 2.1 Shows image of Aluminum Oxide Grinding Wheel taken with 100x Zoom Samsung S22 Ultra

2.1.1 Abrasive

The basic material which constitutes the grinding wheel and determines its hardness or softness is called the abrasive. It is the main cutting compound in the grinding wheel. It has many single point cutting edges which in general combine to form a larger grinding wheel. Thus many single point cutting abrasives constitute to form a grinding wheel tool. Aluminium oxide and Silicon carbide are the two major abrasives used in the manufacture of grinding wheels. These synthetic or manufactured abrasives allow accurate control over the form and physical characteristics of the abrasive grain. It is therefore used in the manufacture of grinding wheels with very specific requirements of performance allied to application needs. Aluminum Oxide This grain is derived by refining bauxite ores in an electric furnace. The bauxite is first heated to drive off moisture and then mixed with coke and iron borings to form the furnace charge. After the mixture has been fused and cooled, the resulting rock–like mass is crushed and screened into various sizes. The colour and the toughness of the abrasive is determined by the amount of impurities (iron oxide, titanium oxide and silica).Toughness is also strongly affected by additives. Aluminum oxide, the most popular abrasive by a wide margin, is usually recommended for grinding most steels, annealed, malleable and ductile iron, and non-ferrous cast alloys. White Aluminum Oxide is a highly refined form of aluminum oxide containing over 99 % pure alumina. The high purity of this abrasive not only bestows its characteristic white colour, but also lends it with its unique property of high friability. The hardness of this abrasive is however 2 similar to that of Brown Aluminum Oxide (1700 – 2000 kg/mm knops). This white abrasive has exceptionally fast and cool cutting and grinding characteristics, especially suitable for grinding hardened or high speed steel in varied precision grinding operations.

Materials used as abrasives are either hard minerals (rated at 7 or above on Mors scale of mineral hardness) or are synthetic stones, some of which may be chemically and physically identical to naturally occurring minerals but which cannot be called minerals as they did not arise naturally Diamond, a common abrasive, for instance occurs both naturally and is industrially produced, as is corundum which occurs naturally but which is nowadays more commonly manufactured from bauxite. However, even softer minerals like calcium carbonate are used as abrasives, such as "polishing agents" in toothpaste.

These minerals are either crushed or are already of a sufficiently small size (anywhere from macroscopic grains as large as about 2 mm to microscopic grains about 0.001 mm in diameter) to permit their use as an abrasive. These grains, commonly called grit, have rough edges, often terminating in points which will decrease the surface area in contact and increase the localized contact pressure. The abrasive and the material to be worked are brought into contact while in relative motion to each other. Force applied through the grains causes fragments of the worked material to break away, while simultaneously smoothing the abrasive grain and/or causing the grain to work loose from the rest of the abrasive.

Zirconium Specialized alumina or Zirconium Aluminium Oxide is a fused mixture of zirconium oxide and aluminium oxide which is used for high production snagging. While sintered alumina, which is extremely tough, is ideal for billet conditioning and very high stock removal snagging operations. Pink Aluminium Oxide Aluminium oxide and chromium oxide alloy is used to combine the cool, low stress grinding action of high purity aluminium with low abrasive wear. The result is a pink grinding abrasive which is slightly tougher and less friable than white abrasive, while still retaining its free cutting properties. This is particularly well suited for grinding abrasive resistant, heat sensitive tool steels. Ceramic Aluminium Oxide Ceramic aluminium oxide abrasive is an extremely tough and durable abrasive produced in a unique sol or seeded gel process. The resulting grain is chemically quite pure, of uniform quality and is comprised of a complex polycrystalline micro structure. This is blended in varied percentages, with more friable conventional aluminium oxide, to make sol – gel wheels. The wheel made out of this abrasive stays sharper because the grains actually discard microscopic crystals during use, which creates new grinding surfaces. Free cutting and with a much longer and more productive life, these wheels are best suited for a variety of applications including centreless, centered, micro-centric, surface, internal, tool and cutter grinding applications. Silicon Carbide Silicon Carbide (SiC) is produced by fusing a mixture of pure white quartz (sand) and fine petroleum coke in an electric furnace. This process is one of synthesizing or combining the sand and coke, in contrast to refining bauxite into aluminium oxide. Again the resulting crystalline mass is crushed and graded by particle size. Silicon carbide abrasives are not only harder than aluminium oxide. Some factors which will affect how quickly a substance is abraded include: Difference in hardness between the two substances: a much harder abrasive will cut faster and deeper

1. Difference in hardness between the two substances: a much harder abrasive will cut faster and deeper

2. Grain size (grit size): larger grains will cut faster as they also cut deeper

3. Adhesion between grains, between grains and backing, between grains and matrix: determines how quickly grains are lost from the abrasive and how soon fresh grains, if present, are exposed

4. Contact force: more force will cause faster abrasion

5. Loading: worn abrasive and cast off work material tends to fill spaces between abrasive grains so reducing cutting efficiency while increasing friction

Use of lubricant / coolant / metal working fluid: Can carry away swarm (preventing loading), transport heat (which may affect the physical properties of the work piece or the abrasive), decrease friction (with the substrate or matrix), suspend worn work material and abrasives allowing for a finer finish, conduct stress to the work piece. A finer or softer abrasive will tend to leave much finer scratch marks which may even be invisible to the naked eye (a "grain less finish"); a softer abrasive may not even significantly abrade a certain object. A softer or finer abrasive will take longer to cut, as it tends to cut less deeply than a coarser, harder material. Also, the softer abrasive may become less effective more quickly as the abrasive is itself abraded. This allows fine abrasives to be used in the polishing of metal and lenses where the series of increasingly fine scratches tends to take on a much more shiny or reflective appearance or greater transparency. Very fine abrasives may be used to coat the strop for a cut-throat razors, however, the purpose of stropping is not to abrade material but to straighten the burr on an edge. [7]. The final stage of sharpening is called polishing and may be a form of superfinishing. Different chemical or structural modifications may be made to alter the cutting properties of the abrasive. Other very important considerations are price and availability. Diamond, for a long time considered the hardest substance in existence, is actually softer than fullerite and even harder aggregated diamond nano rods, both of which have been synthesized in laboratories, but no commercial process has yet been developed. Diamond itself is expensive due to scarcity in nature and the cost of synthesising it. Bauxite is a very common ore which, along with corundum's reasonably high hardness, contributes to corundum's status as a common, inexpensive abrasive.

Thought must be given to the desired task about using an appropriately hard abrasive. At one end, using an excessively hard abrasive wastes money by wearing it down when a cheaper, less hard abrasive would suffice. At the other end, if the abrasive substance is too soft, abrasion does not take place in a timely fashion, effectively wasting the abrasive as well as any accruing costs associated with loss of time. Abrasives are of two types:-

1. Natural Abrasives (Diamond, Quartz, Sand)
2. Artificial Abrasive (Synthetic diamond, Tin oxide, Aluminum oxide, Silicon Carbide.
3. Super abrasives: Super abrasives make up a special category of bonded abrasives designed for grinding the hardest, most challenging work materials

Because carbides, high-speed steels, PCD, PCBN, ceramics and some other materials used to make cutting tools can be nearly as hard as conventional abrasives, the job of sharpening them falls to a special class of abrasives-diamond and the CBN, the super-abrasives.These materials offer extreme hardness, but they are more expensive than conventional abrasives (silicon carbide and aluminum oxide). abrasive grinding wheels have different construction than conventional abrasive wheels. Super abrasives come in the form of grinding wheels and are used when the material being processed is either too hard or too delicate for regular abrasives. Industrial diamonds are one of the most common materials used to create the grinding material. Contrary to popular belief, diamonds are not as rare as marketing campaigns will tell you. Industrial diamonds are not gem quality and usually quite small. They will have visual defects that make them not “pretty enough” to be used in jewelry. After diamonds, cubic boron nitride is the second more durable material for cutting. This is followed by polycrystalline. Synthetic diamonds are also used and fall next on the strength list. These diamonds grow out of a hydrocarbon gas mixture. The final most common material used for superabrasives is nanodiamonds. To get these diamonds a controlled explosion is set off. While the list of industries that use super abrasives is extensive. There are a few industries that are known for being heavy users.

- Oil industry
- Medical

- Aerospace
- Composites
- Automotive
- Electronics

These industries typically manufacture with delicate materials like silicone or very hard materials like metals

Advantages

The most obvious advantage is that these grinding wheels are extremely hard and durable. This allows them to give better performance and greater longevity over regular abrasives. When your wheel lasts longer you will see reduced costs for fixtures and tooling. This opens up your budget up to investing in more machines. You will notice that the wear and cuts on your materials will be even. Because the abrasiveness of the wheel is so strong, it doesn’t develop uneven worn away spots as quickly as regular abrasive wheels. So the output from your production will be consistent. So your manufacturing efforts will produce reliable and consistent results.

2.1.2 Types of Abrasive Grinding Wheels

Straight Grinding Wheels

The straight wheel is the most common mode of a wheel that is found on pedestal or bench grinders. This is the one widely used for centre less & cylindrical surface grinding operations. As it is used only on the periphery, it forms a little concave surface on the piece. This is used to gain on several tools like chisels. The size of these wheels differs to a great extent, width & diameter of its face obviously depends on the category of its work, machines grinding power.

Cylinder or wheel ring Grinding wheels

A cylinder wheel has no center mounting support but has a long & wide surface. Their width is up to 12″ and is used purely in horizontal or vertical spindle grinders. This is used to produce a flat surface, here we do grinding with the ending face of the wheel.

Tapered Grinding wheels

A tapered Grinding wheel is a straight wheel that tapers externally towards the midpoint of the wheel. As this pact is stronger than straight wheels, it accepts advanced lateral loads. The straight wheel with a tapered face is chiefly used for gear teeth, grinding threads, etc.

Straight cup Grinding wheels

This Straight cup wheel forms an option for cup wheels in cutter and tool grinders, having an extra radial surface of grinding is favorable.

Dish cup grinding wheels

In fact, this is used primarily in jig grinding and cutter grinding. It is a very thin cup-style grinding wheel which permits grinding in crevices and slot.

Saucer Grinding wheels

Saucer Grinding Wheel is an exceptional grinding profile used for grinding twist drills and milling cutters. This finds wide usage in non-machining areas, as these saw filers are used by saucer wheels to maintain saw blades.

Diamond Grinding wheels

In diamond wheels, industrial diamonds remain bonded to the edge. This is used to grind hard materials like concrete, gemstones & carbide tips. A slitting saw is designed for slicing gemstones like hard materials.

2.2 Grit or Grain of Grinding wheel

The grit or grain is used to indicate a general size of abrasive for making a grinding wheel. Grits or Grain size is denoted by a number indicates the number of meshes per linear inch of the screen through which the grain pass when they are graded after crushing. Generally, the coarse wheel is used for fast removal of the material and the finely graded wheel should be used to grind Hard, Brittle materials. The different Grits or Grain of the grinding wheel as follows:

Types of Grit	Grit or Grain Size
Coarse	10, 12, 14, 16, 20, 24
Medium	30, 36, 46, 54, 60
Fine	80, 100, 120, 150, 180
Very Fine	220, 240, 280, 320, 400, 500, 600

Table 2.1. Distribution of Grain size

2.3 Grade of grinding wheel

The grade refers to the hardness or strength with which the bond holds the abrasive grains of a grinding wheel in a place. The Grade is indicated by the English alphabet A to Z. A denotes Softest and Z denotes Hardest Grade.

The different grade of the grinding wheel is as follows:

Soft	A, B, C, D, E, F, G, H
Medium	I, J, K, L, M, N, O, P
Hard	Q, R, S, T, U, V, W, X, Y, Z

2.4 Structure of grinding wheel

The structure refers to the spacing between the abrasive grains in the grinding wheel. It is denoted by the number of cutting edges per unit ar of wheel face and size of void spaces between grains. If there is a large number of cutting edges per unit area, the structure is called Dense structure otherwise it is called an open structure. The different structure of the grinding wheel as follows:

Dense	**1, 2, 3, 4, 5, 6, 7, 8**
Open	**9, 10, 11, 12, 13, 14, 15**

Table 2.2: Structure of Grinding Wheel

2.5 Grinding wheel bond

A bond is an abrasive material used to hold abrasive particles together. The bonding material does not cut during the grinding operations. Its main function is to hold the grains together with varying degrees of strength. Bonding materials used for making the wheel is given below:-

Vitrified Bond

Its main constituent is feldspar, which is mixed with some other refractory material to form a strong bond. It is not affected by water, acid oils or ordinary temperature conditions. It is denoted by letter V. Vitrified (V) or Ceramic bonds These are made from clays, feldspar and other fusible materials in a carefully monitored process. Wheels which use this bond have a porous structure and are fired in kilns with O temperatures exceeding 1000 C. Vitrified wheels are unaffected by water, acids oils or normal temperature variation. The porosity and strength of these wheels make them ideal for high stock removal operations. Added to this, Vitrified bonded wheels have a high modulus of elasticity and this rigidity makes them suitable for precision grinding applications.

Silicate Bond

In this bond, silicate is used to bind the abrasive particles. It is denoted by letter S. This type of bond releases abrasive grains readily and thus gives the wheels a comparatively mild and cool cutting action ideal for operations that require minimum heat and for sharpening edged tools.

Shellac bond

In this bond, the abrasive particles are mix with the shellac and then heated Denoted by the letter “E” these are made of both natural and synthetic shellac. Wheels made from these bonds have exceptionally cool cutting properties and are particularly suited for grinding very soft materials such as copper. Shellac bonded wheels are highly recommended for very special grinding applications that require high surface finish such as razor blade and roll grinding.

Resin or Resinoid Bond

It is mostly used for table grinding, swing grinding, snagging grinding, cam grinding, etc. It is denoted by letter B. Resinoid or Organic Bonds are made from phenolic type ‘plastics’ or ‘resins’ and cured in ovens o o under carefully controlled conditions of temperature ranging between 150 c to 200 c. Resinoid wheels are tougher and less rigid than vitrified wheels and are ideally suited for high operating speeds and also for heavy duty of operations, often with the aid of fabric or steel ring reinforcement. Their lower modulus of elasticity helps in achieving finer finishes. Unlike vitrified wheels, resinoid bonded wheels are affected by alkali, humidity or extremes of climatic conditions and tend to deteriorate over a period of time.

Rubber Bond

The abrasive particle is mixed with rubber and sulphur then drawn in the shape after heating. These are used for good surface finishing. It is denoted by letter B. These are made of both natural and synthetic rubber in a varied range of formulations. Used mainly in centreless and control wheels, these are ideally suited for grinding operations that require a high degree of precision and fine surface finish. In wet grinding operations, thin cut-off wheels used to produce burr and burn free cuts are also made of rubber

Metal Bond

It is used for the grinding of very hard metal like tungsten carbide, etc. It is denoted by letter M. Compared to vitrified and organic bonds, the use of metal bonds is very limited. The major use of metal bonds is with diamond abrasive for grinding under harsh conditions. The metal bonded diamond wheel removes material slowly and frequently with high heat generation, but in many applications such as certain glass grinding, abrasive wheel shaping and concrete or stone sawing, the long life outweighs these disadvantages. Metal bonds are also used with aluminum oxide or diamond abrasives to provide conductive wheels for electrolytic grinding.

Oxychloride Bond

This is used without coolant and in file or razor blade industries.

Reinforced Resin Bond

This type of bond mostly used in manufacturing industries and denoted by BF.

2.6 Specification or Nomenclature of Grinding wheel

The Indian standard marking system (IS: SS1-1954) has been used to indicate the various characteristics of a grinding wheel. Each marking consists of 6 symbols, denoting the following characteristics:

1. Abrasive
2. Grain Size
3. Grade
4. Structure
5. Bond type
6. Manufactures record

B A 36 M 6 V 17

Here,

B (Prefix) = Manufacture abrasive type symbols.

A (Abrasive) = [A = Aluminum Oxide], [C = Silicon Carbide], [D = Diamond]

36 (Grain Size) = 4 Types of grain Size.

- Coarse= 10,12,14,16,20,24
- Medium= 30,36,46,54,60
- Fine= 80,100,120,150,180
- Very fine= 220,240,280,320,400,500,600

M (Grade) = Grade categories in to 3 parts.

- Soft= A,B,C,D,E,F,G,H
- Medium=I,J,K,L,M,N,O,P
- Hard=Q,R,S,T,U,V,W,X,Y,Z

6 (Structure) = Structure categories in 2 parts.

- Dense= 1,2,3,4,5,6,7,8
- Open= 9,10,11,12,13,14,15

V (Bond Type) = Vertified Bond

- V= vertified
- B= Resionid
- R= Rubber
- E= Shellac
- S= Silicon
- O= Oxychloride

17 (Suffix) = Manufacturing abrasive type symbol

2.6 Grinding wheel in use

Abrasive Type	**Grit Size**	**Grade**	**Structure**	**Bond**	**Nominal** Ø	**Cutting Velocity** V_c	**Machine Spindle Speed** V_w
A	**60**	**I**	**10**	**V**	**140**	**30**	**3600**

Table 2.3: Grinding wheel specification

2.7 Applications of Grinding wheel

The Grinding machine is a surface finishing Machine in which Grinding wheels are fixed (This is our tool) for surface finish The main application of grinding wheel is to remove the material in the form of tiny chips and make the surface smooth as much as possible. Even the grinding wheel are different type as discussed above and there uses for the different work piece.Grinding process are used in industries for following activities as mentioned here

1. Cylindrical grinding process is used for grinding the outer surface of cylindrical object

2. Centerless grinding process is used for preparing the transmission bushing, shouldered pins and ceramic shafts for circulator pumps.

3. Internal grinding process is used for finishing the tapered, straight and formed holes precisely.

4. There are few special grinders used for sharpen the milling cutters, taps, other various machine cutting tool cutter and reamers.

Some other advantages of using grinding wheel are, Investment is less, Working principle and operation is simple, It does not require additional skills, Surface finishing will be approximately 10 times better as compared to milling and turning process of machining., Dimensional accuracy will be quite good, Grinding process could be performed on hardened and unhardened work piece.

2.8 Difference between cutting wheel and Grinding Wheel

Grinding Wheel	**Cutting Wheel**
The grinding wheel has good strength which avoids cutting improper shape and size.	The normal cutting tool doesn't have abrasive. So it will not provide better finishing accuracy as grinding wheel provides.
The chances of wear and tear are high in cutting wheel	A grinding wheel having low chances of wear and tear.
Price of a grinding wheel is more	The price of the cutting wheel is less than grinding wheel.

Table 2.4: Difference between cutting wheel and Grinding Wheel

2.9 Defects in Grinding Wheel

The defects in the grinding wheel are as follows

We will first study the thermal effects of grinding and these can be covered under two headings namely effects of the wheel and that on the work piece respectively as shown below.

2.9.1 Grinding wheel thermal effects

The main effect of heat on the grinding wheel is the development of the cracks known as grinding cracks. These cracks appear in a direction that is at right angles to the grinding marks. Obviously if these cracks are present in too large a number, the grinding wheel would need to be replaced.

2.9.2 Work piece thermal effects

The work piece is more affected by the heat mainly because it retains a larger proportion of the heat generated during the grinding operation. The work piece can get damaged in various ways including some or all of the following There could be certain reactions which take place at the high-temperatures attained during grinding. These reactions could result in minor changes such as discolouration of the surface due to oxide production, or there could be more serious chemical damage to the work piece. The material properties of the work piece might change due to the application of sudden heat during the process. The material could become brittle or it could get scratched due to ultra-sharp abrasive material. One of the solutions if the work piece is getting overheated is to change the grinding wheel with another wheel which is made up of relatively softer material.

2.10 Other Problems and safety measures

Apart from thermal heating there are several other problems which may arise during the process of grinding. For example the grinding wheel might be wearing too soon and this can be rectified through the use of harder wheel so that its relative hardness is much more compared to the work piece. If the finishing of the work piece is not coming on as desired, that means that there is certainly a matter with the structure of the wheel and it needs to be changed to either a coarse wheel or a finer wheel depending on which problem is arising. If the grinding wheel is not properly balanced, that can also lead to problems such as chatter marks. Grinding is a widespread production process and has long been a fixed part of almost every industrial production environment. During grinding, the parts (work pieces) are literally given the “final polish”. Grinding operations thus contribute greatly to the quality of the finished work piece. However, problems can often occur during the grinding process.

The biggest and most known problem is without doubt grinding burn, which is thermal damage to the rim zone of the part. Grinding burn occurs when too much heat is channeled into the part. Micro cracks and brittle surfaces are often the result. The occurrence of grinding burn depends on a number of factors and the interactions thereof. The most frequent problems during grinding include:

2.10.1 overly high in feed

When grinding parts (work pieces), the process generates a great deal of heat, which is ideally led away with the chips and the coolant lubricant. However, it is impossible to avoid some of the heat entering the part. As long as the heat input into the part is not too great, this poses no problems to the production process. However, if the in feed is too high during grinding and there is insufficient cooling, such a great amount of heat enters the part that grinding burn occurs. Other wrongly selected process parameters may also have the same effect during part machining.

2.10.2 Grinding with too little coolant lubricant

So that a grinding process runs without the occurrence of grinding burn, it is essential to ensure an adequate coolant lubricant supply to the machining zone. A large proportion of the waste process heat is bound and transported away in the coolant lubricant. Only part of the heat generated is taken up by the part, thereby lowering the risk of grinding burn considerably. Frequently, coolant lubricant is used generously in machine tools in an attempt to achieve a process with zero grinding burn. However, even massive use of coolant lubricant will not succeed in preventing grinding burn if it is unable to reach the machining site in a targeted way and at the right exit speed.

2.10.3 Grinding with the wrong process parameters

To ensure that the coolant lubricant optimally reaches the machining zone, a precise ratio between the rotational speed of the grinding wheel and the exit speed of the coolant lubricant from the nozzle needs to be set. Once this operating point has been found, the machining task runs in an optimum way. However, if a parameter, such as the rotational speed of the grinding wheel, is changed, grinding burn usually occurs, as the exit speed of the coolant lubricant must be adapted in such a case to the altered rotational speed. So that this does not need to be carried out manually,

2.10.4 Insufficient cooling during grinding

Cooling during grinding prevents thermal damage to part (workpiece) and the grinding tools. The removal of process heat is achieved via targeted coolant lubricant supply to the machining zone. For this, sufficient coolant lubricant must enter into the machining zone.

Besides the required coolant lubricant volume, the correct alignment of the coolant lubricant nozzles is also relevant. If the coolant lubricant does not enter 100 % into the machining zone, it takes up less process heat and grinding burn may occur. Needs-based, targeted coolant lubricant supply is the basis for achieving optimum cooling during grinding.

Frequently, coolant lubricant supply is achieved via simple coolant lubricant nozzles (e.g. tubes with clamped ends). If thermal damage occurs during production, exchanging the coolant lubricant supply nozzles may solve the problems. Depending on the grinding machine and grinding process, there are a number of coolant lubricant nozzles which ensure needs-based coolant lubricant supply(you can find examples here). Other advantages of optimum cooling may be a higher service life for the grinding tools and higher productivity of the grinding process (e.g. through fewer rejects and larger production figures). [8]

2.10.5 Grinding wheel Loading

The filling of grinded chips between the abrasive particles of the grinding wheel is called loading.

Loading is caused due to

1. Putting work piece by the wheel.

2. Taking cuts that are too deep.

3. Grinding of soft material.

4. By using a wheel of too hard bond and running it too slowly.

If a grinding wheel is highly loaded, the pore spaces become clogged. This means that the grinding wheel can then no longer transport any coolant lubricant and removed chips are no longer led away reliably from the machining site. In such a case, **cleaning nozzles** are recommended in order to make optimum use of the grinding wheel. Cleaning nozzles are nozzles which have been designed especially for removing machining residues from the grinding wheel with the aid of coolant lubricant. Combined nozzle solutions enable the supply of the machining site and cleaning of the grinding wheel using only one coolant lubricant supply line. [9]

2.10.6 Glazing of Grinding Wheel

It is that condition, in which the face or the cutting edge takes a glass like appearance. When a surface of the wheel develops a smooth and shining appearance, it is said to be glazed. This indicates that the wheel is blunt, i.e. the abrasive grains are not sharp. Glazing is caused by grinding hard materials on a wheel that has too hard a grade of bond.

The glazing happens due to following reasons

1. Using hard wheel on hard metals.
2. More speed of revolution or speed of wheel.
3. Less feed of the job
4. Wrong selection of grinding wheel for the desired job material.

CHAPTER 3

GRINDING FACTORS

3.1 Factors Affecting Grinding Process

It's easier than you think. Grinding is a system and the as a whole has many parts to consider. A key component is the wheel .To help you decide where to start, consider seven operating factors.

1. The Material Being Ground
2. The Severity of the Operation
3. Required Finish and Form Accuracy
4. Area of Contact
5. Wheel Speed
6. Coolant Use
7. Machine/Spindle Horse Power

By considering each of these seven factors, you can narrow down your list of options for starting your sharpening process. It's easier than you think. A small list of options for starting the sharpening operation. First things to consider when choosing a grind type The first thing to think about when choosing a grinding wheel specification is what are you going to grind ? What is the material and how hard it is ? Is it easy or difficult to sharpen ? Knowing these elements will help you choose the right type of abrasive, particle properties, appropriate particle size, and bond type.

Knowing the properties of the materials we work with helps us choose the right abrasive and its properties. By convention, aluminum oxide abrasives are used for grinding ferrous metals, and cemented carbides are used for grinding non-metals and non-ferrous metals. Ceramic superabrasives can be used for both, but are generally used when the material being ground requires this type of abrasive and when you want to optimize process performance. Once you know what type ofgrit tostart
with, you can check the abrasiveness of the material. For materials that are easy to sand,

use a strong, durable grit. The material is easy to sharpen, so make sure it doesn't break quickly or break easily so you can use the entire grit to maximize the life of the stone. For materials that are difficult to sand, consider using a mild/brittle grit that is fragile, sharp, andactually sands thematerial.For easy-to-sharpen materials, I would like coarser wheel stone. The grain easily penetrates the material, causing chips to be generated and carried away. Using a larger or coarser grit maximizes cycle time when reducing material. The sharpening material also helps determine the grit for hard-to-sharpen materials. A finer grit is recommended because the smaller particles of penetrate hard materials and form chips more easily than larger blocky ones. Hard-to sharpen materials can damage the abrasive grains, dulling or dulling the sharpness. Penetrating the material requires a sharper tip, so we want to ensure that the particles are expelled before they become too dull and cause metallurgical damage. A harder material should use a softer grit so that the material is always exposed to the sharp grit. [10]

3.2 THE SEVERITY OF THE OPERATION

Now consider the strength of the grinding pressure in grinding zone. The higher the polishing pressure or grit, the more difficult the machining . It is this kind of operation that makes work so well with today's ceramics and super abrasives. As with the material we are grinding , the severity of the operation helps determine the properties of the grain. The final part of the wheel spec, Operational Tightness, helps determine how binding, or harsh, the wheel is. In the case of pressure, the wheel must withstand the forces of the grinding process, so it is inevitable to choose a harder grade for the wheel. To hold the bond, you have to hold it long enough to use the grit so it doesn't release too quickly.

Use mild / crumbly grains for light pressure or less force per particle work. If the operation is not severe, you don't need a durable texture that will just get dull due to rubbing. You need something that breaks down continuously to expose new sharp cutting points, and mild or brittle abrasives do this better by keeping the sharp grit in contact with the material

For light pressure operations, we use finer grit sizes. Since the pressure grain will be lower overall, we need to make sure the grain is still able to fracture properly; if it's too coarse, the grain may not break down and self-sharpen at all When working under light pressure, a softer grade can be used because we the wheel to break down and release the dull grain before it starts to rub and or burn. We also want the wheel to break down to bring new sharp grains to cutting surface so we can perform the required work and get the performance from grain. [11]

3.3 REQUIRED FINISH AND FORM ACCURACY

Abrasive products such as whetstones can be used to quickly iterate and finish shapes. When trying to choose the right wheel spec, you need to see how it works and decide if you want to clear stock quickly or go for a finer finish. Whether the part is simple or has a shape that can be grasped. Knowing these requirements will help you choose the right grinding wheel for your process. Again, the required surface finish, form stability requirements, dimensional tolerances, and removal rates must be considered. By examining these, you can determine the appropriate grit. What the wheel needs to achieve also helps determine the wheel's bond level or hardness. It is clear that for surfaces with low Ra and/or low geometric tolerances, a finer grit is required as the actual grit size provides more points between the workpiece and the wheel. Particle Physics Their moderate size allows them to achieve and hold small radii and complex shapes better than larger or coarser particles.

For surfaces with low Ra values and/or tight geometric tolerances, one would of course want to use a finer grit, as the actual grit size of the grit provides more contact points between the workpiece and the grinding wheel. . [12] This helps with precision finishes that have flatter scratch patterns, resulting in sub-micro inch finishes. Also, the physical size of the particles allows them to achieve and hold small radii and complex shapes better than larger or coarser particles. Use coarser grit when faster material removal rates are required or when geometry and finish are less important. Even if you want a specific finish or shape, you always want to use the coarsest grit possible. Coarse grit requires larger chips, resulting in longer machining cycle times Use coarser grit when faster material removal rates are required or when geometry and finish are less important. Even if you want a specific finish or shape, you always want to use the coarsest grit possible. Coarse grit requires larger inserts, resulting in longer machining cycle times

3.4. AREA OF CONTACT

The fourth factor, contact area, is partially related to the second factor. This is the severity of the job as it takes into account the size (or area) of contact between the workpiece and the grinding wheel. This factor looks at how the force applied to generate chips is distributed over the grinding zone. This is analogous to how surface area relates to pressure in hydraulic systems. When the wheel is applied to the workpiece, the applied force is distributed to all cutting points in the grinding zone. The larger the contact area , the lower the force per reinforcement. Conversely , the smaller the area, the greater the force per grain. Small contact areas require tough and durable particles. The smaller the contact area, the greater the force per grit. So you need abrasives that can withstand these forces without premature breakage or premature wear. Again if it has a high force per grit due to the small contact area ceramic or superabrasive may be better choice. Since the contact area is small, so a finer grit is used. This not only provides more grinding points in the contact area, but also ensures that the relative pressure or grinding force is distributed over many grains. Smaller contact patches generally require the use of harder gear wheels. The smaller the contact area, the greater the force, so the wheel must retain its shape and not release grains too quickly. A hard grit is used to prevent premature wear of the wheel due to the high relative grinding pressure at the contact points. Like Blanchard segments, a milder, less brittle grain is required as the contact area increases and becomes larger. Because more grains are in contact with the workpiece in the grinding zone, the force per grain is reduced, breaking the grains and making sharpening easier. Operations with large contact areas require a coarser grit. This distributes the abrasive power (which is smaller due to its larger area) over fewer grit increasing the pressure per grit and allowing you to work more efficiently. The force helps the particles penetrate the work piece and helps to cause particle breakage/ crushing If necessary.Risk of grain dulling when working with large contact surface. This is due to the lower forces per particle typically found in operations with large contact areas. To compensate for the burning potential associated with blunt particles, the wheel grade should be softer so that the particles can be loosened and replaced before the part is damaged. The last few elements are important, but only useful for fine-tuning or narrowing down your wheel spec options. [13].

3.5. WHEEL SPEED

A fifth factor to consider is wheel speed. The operating speed of the wheel should be considered in terms of surface speed. Use these equations to calculate surface velocity. Wheel speed determines which binding type is best for the speed you need, or if you need a special high speed binding. The operating speed of the wheel should be considered in terms of surface speed. Use these equations to calculate surface velocity. Wheel speed determines which binding type is best for the speed you need A final note on wheel speed. Wheels behave differently depending on their speed. It is generally accepted practice that for every 1000 SFPM (5.08 M/s) change in surface speed, the wheel stiffens or softens by one notch in response to the change in speed.Slow = Soft. Slower wheel speeds result in more force per grit and faster grit and adhesive breakage.Fast = Difficult Higher wheel speeds produce less force per abrasive particle, making both grit and bond more durable and less likely to break as intended.

3.6. COOLANT USE

The sixth factor we consider is coolant consumption. Grinding system coolant affects vitrified and organic (resin) bonded wheels differently and is taken into account when determining wheel grit hardness.When using coolant:Vitrified bonded wheels appear softer because the lubricity of the coolant reduces friction/energy in the grinding zone and helps prevent grain dulling. This keeps it sharper and cuts more freely. Organic (resin bond) grinding wheels work harder because the coolant reduces the heat in the grinding zone. It is the heat of the grind that softens the wheel and allows it to sharpen itself. If you remove or reduce the heat, the wheels will not break as intended.

Without coolant: In dry operation, the abrasive grains rub hard and become dull, making the vitrified bond stronger and generating more heat in the grinding zone, causing burns and other injuries. There is a possibility.

Organic (Resin) Bonded Wheels look soft due to the bonding mechanism. A hot grinding zone softens the wheel faster, which can lead to faster wheel wear and life

3.7. MACHINE/SPINDLE HORSE POWER

The seventh and final factor to consider is horsepower. To determine the degree of binding or hardness of a wheel, the horsepower of the grinder must be considered.

1. High Power - Higher power at the machine spindle requires the use of a harder wheel grade. By making the wheel stiffer, it retains its shape and retains particles as much as possible under higher power/force conditions. You can also use a more durable grit, as enough force/energy should be available to break the grit and sharpen itself.

2. Low Power Consumption - Grinding energy has been found to break up the wheel and grain to work as intended. If the machine is under-powered or the spindle is under-powered it will not be able to apply enough force to break the wheel if necessary, dulling the grain and causing burns and other surfaces. To mitigate this, a softer grade should be used for the wheel. To help with that, you might want to look into a more crumbly grain. There may be situations where one factor steers you in one direction and another steers you in the other.

CHAPTER 4

LITERATURE REVIEW

The grinding process is one of the oldest methodologies to shape materials, dating from the time prehistoric man discovered that he could sharpen his tools by rubbing them against gritty rocks. Capability to shape and sharpen their tools enabled people to survive and make progress. It can be said that Stone Age people were the first abrasive engineers. We still use abrasives in our everyday lives without even giving them a second thought. Even the toothpaste that we use every day to brush our teeth contains a very mild abrasive like hydrated silica which helps to clean our teeth. Detergents that are used to clean our houses have silica or calcium carbonate which is milder abrasives. Apart from their daily usage, abrasives and their capability to shape materials become popular in early nineteenth century with Henry Ford and his desire for mass production. Milling, turning and other machining processes were not accurate enough for precision requirements and surface finish criteria in those days. James Watt, George Stevenson and Ford himself stated the demand for consistency, better control of size and surface finish which were essential for the improvements in design and production engineering. They discovered that abrasives deliver these results and started to use abrasive machining. Synthetic abrasives began to replace the natural abrasives of sandstone, crocus rouge and corundum. These types of abrasives are pure, consistent and can be controlled during abrasive cutter production. It was the usage of aluminum oxide and silicon carbide abrasives which brought us the modern grinding technology and more sophisticated machine tools designed for abrasive machining. By the end of nineteenth century, cubic boron nitride (CBN) and synthetic diamond abrasive particles came into the scene and introduced the Super Abrasive Machining to the manufacturing industry which has serious advantages over conventional grinding methodologies. Nowadays, grinding is a major manufacturing process which accounts for about 20-25% of the total expenditures on machining operations. 70-75% of the precision surface finish operations are conducted by grinding operations in industry. The uniqueness of abrasive machining processes is found in its cutting tool. Grinding wheels and tools are consisted of abrasive grits and softer bond material which holds these grits together in a solid mass. Grinding is undoubtedly the least understood and most neglected machining process in practice. People usually conduct experimental investigations or try-error methodologies rather than trying to understand the mechanism and modeling the process. Reason for that is the belief that the process is too complicated to understand or model by analytical approach. Irregular geometry of the abrasive grits and multiple cutting points in each process, high cutting speeds, depth and width of cut which vary from grit to grit can be the main actors for this belief. Because of the large number of cutting, ploughing and rubbing events occur during the process in a micro scale, it has been noted that the process can be characterized by a typical average grain which is a great simplification. That approach enabled researchers to focus more on grits and try to understand the mechanism between abrasive grits and workpiece material rather than considering the abrasive wheel as a whole. With that development, it can be said that grinding has been transformed from a practical art to an applied science. Malkin, S., 1989, Grinding Technology: Theory and Applications Machining with Abrasives, West Sussex. Ellis Horwood Limited [1].

The high speed grinding refers to advanced technology in machining field. It brought the traditional grinding speed to a revolutionary stage and subverted the view that the grinding sacrifice the efficiency to precision, however, the specificity of chip formation and advantages for high speed grinding are not recognized by demarcation between conventional grinding and high speed grinding which defined by the 50m/s or higher speed value. The bottleneck problems of high temperature and burn are not solve in high speed grinding of high strength and toughness difficult-to-machining material, the material removal rate is still not improved for grinding machining filed by taking advantage of the high speed grinding technology. Thus, in this paper, the chip formation of high speed grinding is intensive studied by the single-grain tests, based on this, the countermeasure advanced in this paper to break the bottleneck is that the process of high speed grinding is optimized by adopting the regular abrasive distribution grinding wheel. then the topography model of the regular abrasive grinding wheel and the grinding process models are set up, these models are to be perfect by analyzing the relationships among grinding speed, the maximum undeformed chip thickness, and grinding force, specific energy, grinding temperature in the high speed grinding experiments. Fundamental Research on the High Speed Grinding with Regular Abrasive Distribution Wheel Doctoral Thesis by Lin Tiang (Nanjing University of Aeronautics and Astronautics [2]. The high speed grinding refers to advanced technology in machining field. It brought the traditional grinding speed to a revolutionary stage and subverted the view that the grinding sacrifice the efficiency to precision, however, the specificity of chip formation and advantages for high speed grinding are not recognized by demarcation between conventional grinding and high speed grinding which defined by the 50m/s or higher speed value. The bottleneck problems of high temperature and burn are not solve in high speed grinding of high strength and toughness difficult-to-machining material, the material removal rate is still not improved for grinding machining filed by taking advantage of the high speed grinding technology. 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During high speed grinding, the chip of single grain formed at a very high strain rate, so the effects of thermal-mechanical coupling are considered. Therefore, according to the limitations of traditional method of single-grain scratching tests, innovatively presented the two single-grain grinding test method, the “single step method” and “two steps method”. The chip formation process were observed and the critical thickness of chip formation were quantificationally analyzed for the first time, and the characteristic of shear deformation of serrated grinding chips and swelling rate were intensively analyzed. The results indicate that the mechanism of chip formation change by increasing in grinding speed and maximum undeformed chip thickness. This paper made the research on the traditional modeling and analysis of grinding process and pointed out their application limitation. then an research ideas was advanced in the paper, firstly, the high speed grinding process model based on the regular abrasive distribution grinding wheel were set up, and then the relationship were built up taking the grinding speed and maximum undeformed chip thickness as ligament, finally the optimized grinding parameters was achieved. In the paper the characteristic elements of regular abrasive distribution grinding wheel were modeled, and the related elements models for grinding process such as the number of active grains, maximum undeformed chip model, grinding force, average heat flux in grinding zone etc. were set up. At last the high speed grinding application system based on the regular abrasive distribution grinding wheels was established. Under the guidance of research thinking which is that the “grinding process optimization based on the regular abrasive distribution grinding wheel”, the high speed grinding experiments for TC4 titanium alloy and GH4169 superalloy were systemically carried out by using the regular abrasive distribution grinding wheel. The experiments show that when the speed ratio or the maximum undeformed chip thickness is a constant, the grinding force and specific energy still keep constant with an increasing in grinding speed. The specific energy decreases with enhancing the maximum undeformed chip thickness. the regular abrasive distribution give the grinding wheel superiority in grinding force and grinding temperature reduction to brazed abrasive wheel and ceramic bond wheel. These results indicate that the high speed grinding has great advantage and provide direction to optimize the high speed grinding parameters of TC4 titanium alloy and GH4169 superalloy. This direction is that based on the regular abrasive distribution grinding wheel, under the condition of keeping the speed ration or the maximum undeformed chip constant and non-burn in grinding process, the material removal ratio can be improved when increasing grinding speed, which may be encouraging. According to the material constitutive relation, the size effect and speed effect on the critical thickness of chip formation, specific grinding force, grinding force, specific energy and grinding temperature were analyzed in grinding with single-grain tests and grinding with wheel. For the first time, the section of grinding process model based on the material constitutive relation was set up. In this paper, It is proposed that the speed effect and size effect on grinding force, specific energy and grinding temperature were explained resulting from the factors as strain hardening, strain rate strengthening thermal softening and also the micro-defects of the contacting region material. The analysis equations of specific grinding force, grinding force, specific energy were deduced on account of the material constitutive relation and grinding process model. The method and formula of staged moving heat source plane were systematically established through analyzing the heat generation and heat transfer in high speed grinding zone. The deductive thinking and results are considered to successfully make clear the high speed grinding mechanism which explained by impact dynamics and metal processing theories. [5]

CHAPTER 5

METHOD AND EXPERIMENTS

5.1 Experimental setup

The overall experiments are being done on a Praga Tool and Cutter Grinding machine with a spindle speed of 1200RPM, 1500RPM and 1800RPM. The grinding wheel being used is compatible for Mild Steel Flat.

Fig 4.1 Setup for grinding wheel on Tool and cutter grinding wheel

The workpiece used is mild steel flat. The cutting tool in use is Aluminium based grinding wheel with given specifications. Machining takes place at different speeds and at different depths of cut keeping feed constant. The table summarizes the settings for the most important machining parameters In this present paper, effort is made to find the effect of dressing parameters on the grinding wheel topography and it is measured in terms of minimum surface roughness (Ra) during the surface grinding for mild steel bar.. An experimental design based in L9 orthogonal array is used to check the interactions between the factors. In the present work, experimental results were used to find the analysis of variance (ANOVA) which explains the significance of the parameters on the responses. To establish the suitable correlation between the input parameters and the response surface roughness and Finally, the predicted value is validated and compared with experimental result

PARAMETERS	VALUE
FEED (mm/rev)	0.4
SPEED (rpm)	3600, 4800, 5400
DEPTH OF CUT (mm)	0.02, 0.04, 0.06 mm

Table 5.1: Parameters considered in Experiments

5.2 Experimental Design

In a whole block randomized design it is possible to reduce error variance by creating blocks in which the experimental units of the block are relatively more similar than the dependent variable of interest to the user. The main goal of block generation is to eliminate variations due to experimental errors and block variations. An experimental unit or subject corresponds to a plot and a block consists of k subjects that are identical for a given variable. Here each block consists of k items matching a given variable. Subjects within a block are therefore more homogeneous than randomly selected subjects. The purpose of this local control is to create uniformity within each r block and consequently heterogeneity between blocks. Variations due to block differences are eliminated by experimental error.

The experiment was designed using the Taguchi method which uses OA (orthogonal arrays) to explore the parametric space with some experiments. Two parameters were selected in this study: cutting speed and depth.

Selection of a particular OA (orthogonal array) is based on the number of levels of various factors. Here, 3 parameters each at 3 levels, therefore Degree of Freedom (DOF) can be calculated as:

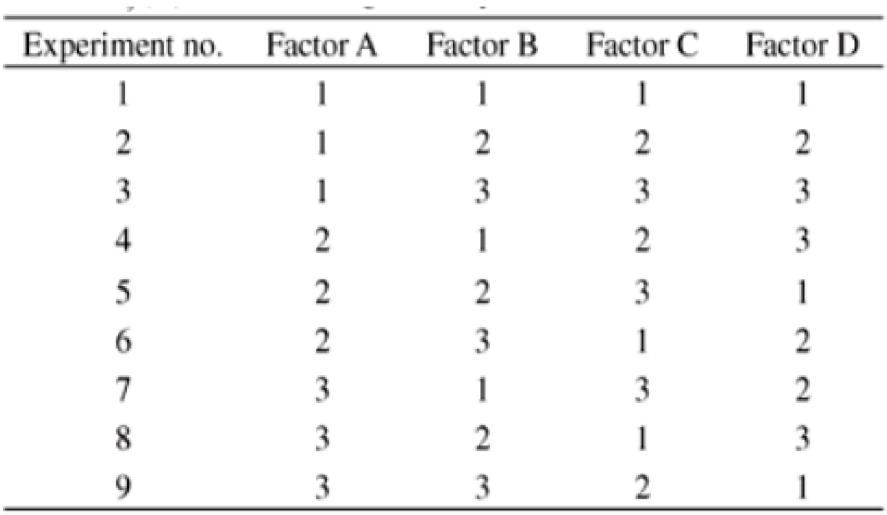
$$\mathbf{(DOF)_R = P\ (L - 1)}$$

Where, P = number of factors

L = number of levels

$$\mathbf{(DOF)_R = 3\ (4 - 1) = 9}$$

The total DOF for OA must be greater than or equal to the total DOF required for the test where L_9 (3^4) OA is specified (see table 2). Each processing parameter is assigned to a column of OA and 9 groups of processing parameters are generated. The response variables selected for this study were: surface roughness and tool tip temperature.



Experiment no.	Factor A	Factor B	Factor C	Factor D
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

Table 5.2: L_9 (3^4) Standard orthogonal Array

Experimental setup for first exercise with machine spindle speed of 1800 RPM and Depth of cut varying from 0.2 mm, 0.4mm and 0.6mm is taken feed remains constant. The surface finish is done on a job of area 240$cm^2$and average time taken is almost 15 minutes. The surface finish is checked by Dial Test Indicator and each value is noted. The experimental calculation is done by Taguchi’s method.

Exercise 1							
Depth Of Cut: 0.2, 0.4, 0.6mm							
Area of Job: 240cm^2							
Time Taken for Surface finishing: 15min.							
Abrasive Type	**Grit Size**	**Grade**	**Structure**	**Bond**	**Nominal Ø**	**Cutting Velocity V_c**	**Machine Spindle Speed V_w**
A	**60**	**I**	**10**	**V**	**140**	**30**	**1200**

Table: 5.3 Parameters for first set of combinations

Figure 4.2. Experimental setup for Surface grinding

Figure 5.3. Finished work piece after Surface grinding

SPEED (RPM)	**DEPTH OF CUT(mm)**			**TOTAL SUM**
	0.2	**0.4**	**0.6**	
1200	.09	.08	.10	**1.85**
	.15	.11	.15	
	.15	.10	.14	
	.16	.10	.15	
	.14	.09	.14	

Table 5.4: Experimental result for Surface Roughness as per Taguchi's method

Experimental setup for second exercise with machine spindle speed of 1800 RPM and Depth of cut varying from 0.2 mm, 0.4mm, 0.6mm is taken feed remains constant. The surface finish is done on a job of area 240$\boldsymbol{cm^2}$and average time taken is almost 15 minutes. The surface finish is checked by Dial Test Indicator and each value is noted. The experimental calculation is done by Taguchi's method.

<table>
<tr><td colspan="8">Exercise 2</td></tr>
<tr><td colspan="8">Depth Of Cut: 0.2, 0.4, 0.6mm</td></tr>
<tr><td colspan="8">Area of Job: 240$\boldsymbol{cm^2}$</td></tr>
<tr><td colspan="8">Time Taken for Surface finishing: 15min.</td></tr>
<tr><td>Abras Type</td><td>Grit Size</td><td>Grade</td><td>Structure</td><td>Bond</td><td>Nominal Ø</td><td>Cutting Velocity V_c</td><td>Machine Spindle Speed V_w</td></tr>
<tr><td>A</td><td>60</td><td>I</td><td>10</td><td>V</td><td>140</td><td>30</td><td>1500</td></tr>
</table>

Table 5.5: Parameters for Second set of combinations

Figure 5.4: Experimental setup for Surface grinding

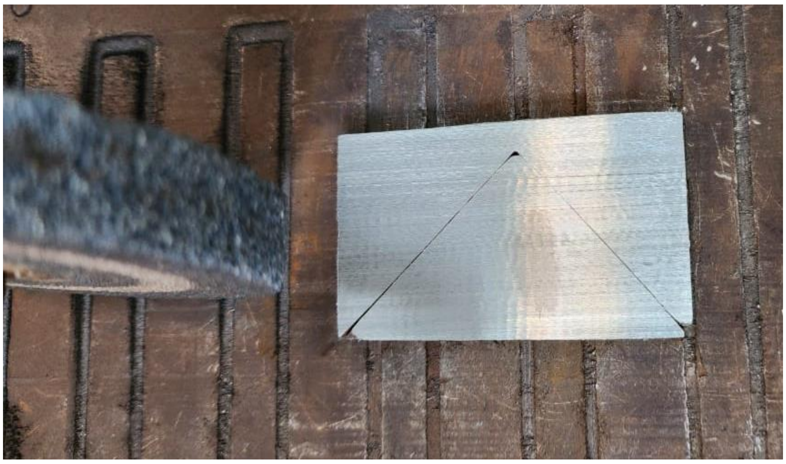


Figure 5.5: Finished work piece after Surface grinding

SPEED (RPM)	**DEPTH OF CUT(mm)**			**TOTAL SUM**
	0.2	**0.4**	**0.6**	
1500	.08	.05	.10	**1.85**
	.10	.06	.09	
	.10	.06	.09	
	.11	.05	.10	
	.10	.06	.11	

Table 5.6: Experimental result for Surface Roughness as per Taguchi's method

Experimental setup for third exercise with machine spindle speed of 1800 RPM and Depth of cut varying from 0.2 mm, 0.4mm, 0.6mm is taken feed remains constant. The surface finish is done on a job of area 240$\boldsymbol{cm^2}$and average time taken is almost 15 minutes. The surface finish is checked by Dial Test Indicator and each value is noted. The experimental calculation is done by Taguchi’s method.

Exercise 3							
Depth Of Cut: 0.2, 0.4, 0.6mm							
Area of Job: 240cm^2							
Time Taken for Surface finishing: 15min.							
Abrasive Type	**Grit Size**	**Grade**	**Structure**	**Bond**	**Nominal Ø**	**Cutting Velocity** V_c	**Machine Spindle Speed** V_w
A	**60**	**I**	**10**	**V**	**140**	**30**	**1800**

Table 5.7: Parameters for Second set of combinations

SPEED (RPM)	**DEPTH OF CUT(mm)**			**TOTAL SUM**
	0.2	**0.4**	**0.6**	
1800	.02	.03	.06	**1.85**
	.05	.04	.07	
	.05	.05	.06	
	.04	.04	.06	
	.06	.03	.07	

Table 5.8: Experimental result for Surface Roughness as per Taguchi’s method

5.3 Experimental design of Aluminum oxide grinding wheel

In this case the experimental results are the surface roughness obtained on the surface of mild steel flat using Dial Test Indicator.

SPEED (RPM)	**DEPTH OF CUT(mm)**			**TOTAL SUM**
	0.2	**0.4**	**0.6**	
1200	.09	.08	.10	**1.85**
	.15	.11	.15	
	.15	.10	.14	
	.16	.10	.15	
	.14	.09	.14	
	.08	.05	.10	

1500	.10	.06	.09	**1.26**
	.10	.06	.09	
	.11	.05	.10	
	.10	.06	.11	
1800	.02	.03	.06	**0.73**
	.05	.04	.07	
	.05	.05	.06	
	.04	.04	.06	
	.06	.03	.07	
TOTAL SUM	**1.40**	**0.95**	**1.49**	**3.84**

Table 5.9: Experimental result for Surface Roughness as per Taguchi's method

S.NO	**SPEED**	**DOC**	**ROUGHNESS**					**AVG Roughness**
			R1	**R2**	**R3**	**R4**	**R5**	
1	**1200**	**0.2**	.09	.15	.15	.16	.14	**0.138**
2	**1200**	**0.4**	.08	.11	.10	.10	.09	**0.096**
3	**1200**	**0.6**	.10	.15	.14	.15	.14	**0.136**
4	**1500**	**0.2**	.08	.10	.10	.11	.10	**0.098**
5	**1500**	**0.4**	.05	.06	.06	.05	.06	**0.056**
6	**1500**	**0.6**	.10	.09	.09	.10	.11	**0.098**
7	**1800**	**0.2**	.02	.05	.05	.04	.06	**0.044**
8	**1800**	**0.4**	.03	.04	.05	.04	.03	**0.038**
9	**1800**	**0.6**	.06	.07	.06	.06	.07	**0.064**

Table 5.10: Experimental result for Surface Roughness as per Taguchi's method

The computation procedures of the design of experiment for Surface Finish are given below:

i. Correction Term, C = $(3.84)^2 /45 = 0.32768$

ii. Total sum of squares, $SS_{Total} = (.09)^2 + (.15)^2 + \ldots\ldots\ldots + (.07)^2 - C$

$= 0.08514 – 0.32768 = 0.24254$

iii. DOC sum of squares, $SS_{DOC} = (1.40)^2 /15 + (0.95)^2 /15 + (1.49)^2 /15 - C$

$= 0.01212$

iv. Speed sum of squares, $SS_{Spd} = (1.85)^2 /15 + (1.26)^2 /15+ (0.73)^2 /15 - C$

$= 0.04189$

v. $SS_{SPEED}*SS_{DOC} = (0.69)^2/5 + (0.48)^2/5 + \ldots\ldots + (0.32)^2/5 - C - SS_{DOC} – SS_{Spd}$

$= .039762$

vi. Error sum of squares, $SS_{error} = SS_{Total} - (SS_{DOC} + SS_{Spd} + (SS_{DOC}*Spd))$

$= 0.24254 - (.01212 +.04189 + .00050)$

$= 0.18802$

CHAPTER 6

RESULTS AND DISCUSSION

The roughness parameters are computed from the co-efficient calculated for the plane, by calculating the average roughness (Ra). As described in ASME B46.1, Ra is the arithmetic average of the absolute values of the profile height deviations from the mean line , recorded within the evaluation length. Simply put Ra is the average of a set of individual measurements of a surfaces peak and valleys. Considering that Zi is the height and it is calculated as

$$\text{Zi} = b_0 + b_1 * P_1\text{x} + b_2 P_2\text{y}$$

The Z calculated for Ra is absolute; however to calculate peaks and valleys, positive and negative values are considered in relation to the Z of the plane. This non absolute value is the basis for the computation of the other roughness parameters. The digital approximation is:

$$\text{Ra} = \langle Z1|Z2|Zn\rangle \,/\, \text{n}$$

RMS

As described in ASME B46.1, RMS is the root mean square average of the profile height deviations from the mean line, recorded within the elevation length.

$$\text{Rq} = \{[\,Z_1^2 + Z_2^2 + Z_n^2\,]\,/\text{n}\}\ {}^1\!/_2$$

The experiments carried out here show the deviation of Dial Test Indicator at various point of job. The least count of DTI being 0.01mm and length of job being 60mm, at various locations reading have been noted. The calculation of Ra value tells us about the surface roughness zone in which our finished job lies.

5.1 Variance of the design of experiment for Grinding Wheel

The analysis of variance of the design of experiment for Grinding Wheel is summarized in table:

SOURCE OF VARIATION	**SUM OF SQUARE**	**%C**
SPEED	0.04189	70.26
DOC	0.01212	28.87
SPEED*DOC	0.039762	0.803
ERROR	46.03	0.066
TOTAL SUM	69633.24	100

Table 6.1: Analysis of variance

1. From the ANOVA table, it is clear that speed is the most significant parameter followed by depth of cut. However the interaction of speed*depth of cut has least effect
2. From the above Taguchi,s experiments it can be concluded that
3. For low spindle speed and very low depth of cut the Roughness value is more than the Other two values. Which shows that the best finish is not achieved and thus is not the Ideal parameters for precision grinding.
4. For medium spindle speed and low depth of cut the Roughness value is less than the Other two values. Which shows that the best finish is achieved and thus is the ideal? Parameters for precision grinding.
5. For high spindle speed and high depth of cut the Roughness value is more than the other two values. Which shows that the best finish is not achieved and thus is not the Ideal parameters for precision grinding.

Some other conclusions carried out is:

Since spindle speed is very high in any case, very precise feed rate is to be provided. The surface finish is very much heavily dependent on the feed rate. High feed rate and and high spindle speed can cause chatter marks or burn marks on the job. At much higher Spindle speed Depth of Cut should be minimized as otherwise burn mark will be a common phenomenon and job will fail. At every spindle speed, depth of cut with steady feed rate (in case of manual feeding) is the key to best surface finish. Thus no matter how much time it takes but Depth of cut has to be taken in consideration with amount of material to be removed (finished), the type of finish required and the utility of product. The effect of heat effected zone at the point of contact of tool and job is not considered and not taken into account. But in ideal scenario effect of heat has very much to do with the finish of job. An ideal suitable coolant has to be provided with good nozzle flow direction at the point of contact of job and grinding wheel. Since work area is small and very less time is being taken in finishing the job, very less effect is to be sheen and thus not taken into account while carrying out the experiment

Thus it can be concluded that at a high cutting speed here in this case it is 1800 RPM with an optimum value of Depth Of Cut, here it being 0.4mm can give us optimum result in one go. Thus it also proves to be economical as work completion time is less with less wear out and less dressing required. Job is ultimately super smooth and super finished maintain the accuracy, and grinding wheel requiring very less dressing.

CHAPTER 7

CONCLUSION

From the ANOVA table, it is clear that speed is the most significant parameter followed by depth of cut. However the interaction of speed*depth of cut has least effect Since spindle speed is very high in any case, very precise feed rate is to be provided. The surface finish is very much heavily dependent on the feed rate. High feed rate and and high spindle speed can cause chatter marks or burn marks on the job.At much higher Spindle speed Depth of Cut should be minimized as otherwise burn mark will be a common phenomenon and job will fail. At every spindle speed, depth of cut with steady feed rate (in case of manual feeding) is the key to best surface finish.Thus no matter how much time it takes but Depth of cut has to be taken in consideration with amount of material to be removed (finished), the type of finish required and the utility of product.

Scope for Future Aspects

In this thesis effect of depth of cut and cutting speed on mild steel was studied. The grinding wheel was dressed with diamond dresser after every single experiment. So there are many parameters which can still be considered, taking in mind each and every aspect of machining process. Some of the aspect may be:-

Feed Rate:- Since time taken to complete finishing of whole job is same, feed rate through manual has been kept same throughout the exercise. An optimum feed has been taken i.e. 0.04m/sec which is quiet ideal. Faster feed can give burn marks on the job. Lower feed can give cutting marks on the job. Spindle Speed can also be verified to give further more options to have better finish.

Loading and Truing

A new grinding wheel is mounted on grinding machine, which has all fresh cutting edges. Since all the cutting edges are exposed for the cutting operation, it can heavily impact the finish of the work piece. A grinding wheel dressed several times before every operation has other challenges to face. Such as grinding wheel loading. The chips get stuck between the cutting edges, thus affecting the cutting and finishing quality of grinding wheel. A grinding wheel is trued to make it even over the surface thus allowing whole surface of grinding wheel to perform the cutting operation. Glazing (blunt edges) is removed to get new cutting edges Figure shows a freshly mounted wheel with all the cutting edges.

A used wheel develops many irregularities such as loading, glazing and axial dislocation. These problems can be overcome by dressing and truing. Figure shows a used wheel which has developed above problems. Thus study of impact of dressing and truing on cutting and finishing operation is well left for future study.

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